

UNIVERSITY OF MICHIGAN

K-SERIES EMISSION SPECTRA FOR THE ELEMENTS
FROM TA(73) TO BI(83)

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MENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE
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BY

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ABSTRACT

The specially designed water-cooled tube enabled currents of 8 milliamp. at 150 kv to be used. By connecting the same rheostat in the primaries of both high-tension and filament transformers, irregularity due to hot spots on the target was automatically smoothed out. An automatic electromagnetic cutout prevented excessive current when gas developed. With these arrangements, accurate measurements were made of the K-lines for all elements from Ta(73) to Bi(83) excepting Hg, the elements being placed in sheets or layers on the thin copper target. The $\sqrt{\nu/R}$ values plotted as a function of atomic number give practically straight smooth curves, as is to be expected. The differences in the ν/R values for the a and a' lines agree well with the corresponding values for $L\beta$ and La' . The corresponding wave-length differences are nearly constant and equal to 4.85.

UNTIL very recently the only two elements of the group from Ta(73) to Bi(83) for which the K-series emission wave-lengths had been measured were tungsten and platinum. Duane and Stenstrom,¹ Siegbahn,² Cork,³ Lilienfeld and Seeman,⁴ DeBroglie,⁵ and Rogers⁶ have measured one or both of these elements. Just recently Rechou⁷ has published measurements on the elements from tantalum to uranium.

APPARATUS

The spectrometer was of the type used by one of us in a previous investigation but was made larger. The distance between the second slit and the photographic plate was 75.593 cm. This gave a much larger separation of the lines on the plate. The plate holder was a rectangular frame machined out of one piece of solid brass and set optically perpendicular to the axis of the spectrometer. The photographic plate was held against the back face of the plate holder by three springs so that the emulsion side of the plate which faced the slit

¹ Duane and Stenstrom, Proc. Nat. Acad. **6**, 477 (1920).

² Siegbahn, Spectroscopy of X-rays, p. 104 (1925).

³ J. M. Cork, Phys. Rev. **25**, 197 (1925).

⁴ Lilienfeld and Seeman, Phys. Zeit. **19**, 269 (1918).

⁵ DeBroglie, Comptes Rendus **169**, 134 (1919).

⁶ Rogers, J. S., Roy. Soc. Victoria, Proc. **34**, 136.

⁷ Rechou, M. G., Comptes Rendus **180**, 1107 (1925).

system was always the same distance from the second slit. X-rays were allowed to fall only on one side of the crystal at a time, thus giving all of the lines of the K series on one side of the plate simultaneously; the other half of the photographic plate being covered by a lead plate to prevent fogging during this time. The crystal was calcite and about 3 mm thick.

The x-ray tube was made with the target and filament removable at ground joints which were sealed with stopcock grease. The total tube length was about 18 inches, with the removable target 8 inches long and the ground stopper for the filament leads about 6 inches long. The target was of special design with two compartments so arranged that the part of the target which was in contact with the ground joint was always filled with the inflowing cold water while the heated water from the hot end of the target was carried by a tube through the center of the outer compartment and thus did not heat the joint. This enabled the use of tube currents as large as 6 to 8 milliamp. at 150 kv when elements with a high melting point were being used on the target. The filament was a spiral form of tungsten wire held in the filament container of a regular Coolidge tube which had been adapted to this apparatus. The lead wires were sealed in the outer end of the stopper to prevent puncturing such as often happened when the wires were sealed in at the inner end of the stopper. As both ends of the tube were different in potential from ground by half of the applied voltage, the leak through the target cooling water to ground was very large. With 55 feet of quarter-inch continuous glass tubing well insulated from ground the leak was from 6 to 7 milliamp. at the highest voltages.

The pumping system consisted of a two-stage mercury vapor pump with liquid air trap, backed by a rotary oil fore-pump. When the pumps and tube were working well, an x-ray vacuum could be obtained in about two or three hours. The time was shorter for the lower voltages.

The potential for the tube was obtained from a Victor Special 200 kv transformer and mechanical rectifier. The filament current was supplied by a Victor filament transformer. The voltage was regulated by means of an autotransformer and a rheostat in series with the primary of the high tension transformer.

Under ordinary conditions the tube current was unsteady, due to hot spots being produced on the target when some small bit of the powder became slightly detached from the target or when the sheet metals became slightly loosened and melted. This was overcome by

using the same rheostat as part of the resistance of both the high tension primary and the primary to the filament transformer. Thus when the tube current tended to increase, the fall of potential over this common part of the resistance was increased and the filament current thereby diminished. This stabilizer held the current very steady as long as the voltage remained constant.

An electromagnet was placed with its exciting coil in parallel with the primary of the high tension transformer, and arranged to hold the primary circuit closed. When gas developed in the tube, as often happened, the tube current increased very much, causing the potential difference at the terminals of the high tension primary to fall; this allowed the electromagnet to open and thus break the circuit. The electromagnet was very quick acting and saved the tube as well as the rest of the apparatus from overheating. With these two devices it was possible to leave the apparatus for an indefinite period without fear of injury. A clock attached to the arm of the electromagnet was arranged to stop when the circuit was opened so that the time of exposure could be accurately determined. It was found that about 10 milliamperes-hours at the proper voltage were necessary to give a strong exposure. The potential used varied from 120 kv for Ta to 156 kv for Bi.

All of the elements were obtained in as pure a form as possible. Tantalum, platinum, and gold were in sheets and were held on the face of the target. Platinum and gold were soldered to the copper face while tantalum, which could not be soldered, was wedged into a groove in the target. Osmium and iridium were powdered and rubbed onto the target. Two or three applications of the powder for each plate were sufficient. Thallium, lead and bismuth were flowed onto the target like solder. With all the elements, and especially with the last three, considerable difficulty was experienced because of the intense heat melting the element and sputtering the walls of the tube, causing it to puncture. It was not possible to get any of the elements in sufficiently good thermal contact with the target to avoid melting and sputtering. The face of the target was only about 2 mm thick and was made of copper to conduct the heat better and yet the high melting point metals became white hot at the focus. Since thallium, lead, and bismuth have such low melting points a very small tube current had to be used to avoid excessive sputtering. The tube was often taken down and cleaned, for it punctured easily if the walls became coated with sputtered metal.

MEASUREMENTS AND ACCURACY

This investigation was carried out in the second basement of the new Physics building where the temperature varied not more than 2°C at any time and usually not more than one degree. The plates and the length of the spectrometer were measured at the same temperature thereby eliminating any temperature effects. The length of the spectrometer was measured with a "Starrett" micrometer scale capable of measuring to 76.5 cm. This measurement was checked by making a rod with an adjustable end piece which could be set at the exact length between the slit and the plate and then measured on the same comparator as that used in measuring the plates. Grooves were filed out of the rod down to the center so that the rod could be measured in steps without having to change the focus of the telescope.

A distance of .25 mm on the plate corresponded to 1 x-unit and since the plates could be measured to 0.01 mm with a Gaertner comparator the measurements are certainly accurate to 0.1 x-unit. Four different crystals were used during the course of the investigation but no appreciable difference was observed in the values for the tungsten lines obtained.

RESULTS

Table I gives the values of the wave-lengths obtained. The values for tungsten obtained by one of us³ previously, corrected for an error in the micrometer scale, as well as those of Duane and Stenstrom and Siegbahn are included for comparison. All of these values are corrected where necessary for any differences in the value of the crystal grating constant. The values obtained by Rogers⁶ for platinum are also included.

TABLE I

Wave-length values in x-units of K series lines

Element	α'	α	β	γ	Investigators
73 Tantalum	219.73	214.88	189.91	184.52	Present
74 Tungsten	213.45	208.62	184.22	178.98	Present
	213.48	208.67	184.28	179.07	Duane and S.
	213.45	208.60	184.35	178.87	Cork
	213.52	208.85	184.36	179.40	Siegbahn
	201.31	196.45	173.61	168.75	Present
76 Osmium	195.50	190.65	168.50	163.76	Present
78 Platinum	190.04	185.23	163.70	158.87	Present
	189.54	185.11	164.37	159.55	Rogers
	184.83	179.96	159.02	154.26	Present
79 Gold	174.66	169.80	150.11	145.39	Present
82 Lead	170.04	165.16	146.06	141.25	Present
83 Bismuth	165.25	160.41	142.05		Present

Since the temperature of the laboratory remained practically constant at 22°C the value of the grating constant given by Siegbahn²

$\log 2d = 0.78235$ was used. No correction is made in the values of Table I for the effect of the refraction of the x-rays by the crystal. The magnitude of this correction is indicated by the following equation, $\lambda = 2d (1 - 0.000135) \sin \theta$. Thus the α line of tantalum 214.88 would become 214.85 x-units.

In Table II are given the frequency values ν/R , where ν is the reciprocal of the wave-length expressed in angstrom units and R is the Rydberg constant 109,737. These values are proportional to the energies emitted when the corresponding electron shifts occur.

TABLE II

 ν/R values of K series lines

Element	α'	α	β	γ
73 Tantalum	4147.3	4240.8	4798.6	4938.6
74 Tungsten	4269.2	4368.2	4946.7	5092.4
76 Osmium	4526.7	4638.8	5249.0	5409.4
77 Iridium	4661.4	4779.8	5408.1	5564.7
78 Platinum	4795.9	4919.9	5566.8	5731.9
79 Gold	4930.2	5063.9	5730.5	5907.4
81 Thallium	5217.4	5366.8	6070.6	6267.9
82 Lead	5359.4	5517.8	6239.1	6451.3
83 Bismuth	5514.6	5680.9	6415.3	

Table III gives the values of the square root of the frequency terms, $\sqrt{\nu/R}$. When these values are plotted with atomic number the curves shown in Fig. I are obtained. These points, shown by circles, fall very closely on smooth curves. The values obtained by Réchou, when they differ enough from our values to be indicated separately, are indicated by crosses. It is evident that some of his measurements show large deviations.

TABLE III

 $\sqrt{\nu/R}$ values of K series lines

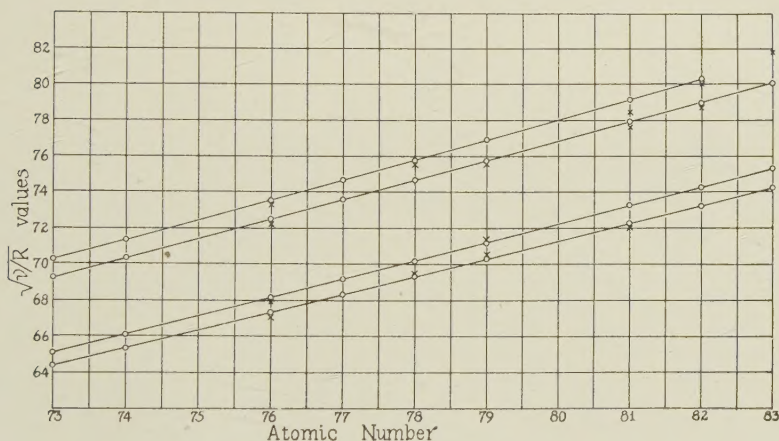
Element	α'	α	β	γ
73 Tantalum	64.40	65.12	69.27	70.28
74 Tungsten	65.34	66.09	70.33	71.36
76 Osmium	67.28	68.11	72.47	73.49
77 Iridium	68.28	69.14	73.54	74.62
78 Platinum	69.25	70.14	74.61	75.71
79 Gold	70.22	71.16	75.70	76.88
81 Thallium	72.23	73.26	77.91	79.17
82 Lead	73.21	74.28	78.99	80.32
83 Bismuth	74.26	75.37	80.10	

Table IV gives a comparison of the differences of the frequency values ν/R for the $K\alpha'$ and $K\alpha$ lines shown in column 2, and the results obtained by taking the frequency differences of the $L\alpha'$ and the $L\beta$ lines which represent the same energy differences, shown in column 3. The two columns agree fairly well. The values obtained by Réchou are also shown in column 4. In column 5 is given the wave-length difference ($\Delta\lambda$) between the $K\alpha'$ and $K\alpha$ lines. This wave-

length difference for the relativity doublet is nearly constant for elements of large atomic number.

TABLE IV

Element	Doublet differences		$\Delta(\nu/R)$ $L\beta - L\alpha'$	$\Delta\lambda$ $K\alpha' - K\alpha$ (x-units)
	$\Delta(\nu/R)$ $K\alpha' - K\alpha$			
	Our data	Rechoú		
73 Tantalum	93.5	96.8	92.7	4.85
74 Tungsten	99.0	100.6	98.5	4.83
76 Osmium	112.1	105.7	111.1	4.86
77 Iridium	118.4	113.0	118.6	4.85
78 Platinum	124.0	117.7	125.9	4.81
79 Gold	133.7	140.3	135.6	4.87
81 Thallium	149.4	172.3	150.5	4.86
82 Lead	158.4	158.9	160.0	4.88
83 Bismuth	166.3	164.7	169.7	4.84

Fig. 1. $\sqrt{\nu/R}$ values as a function of atomic number.

The β line in every case appears much wider than the α' and the α lines, thereby indicating that it is complex. On some plates the components β and β' were sufficiently well defined to be separately measurable, but these are not recorded.

The x-ray tube was made of Pyrex glass which is supposed to be free from lead, but on every plate set for the measurement of short wave-lengths the lead K absorption edge appeared. This cut off completely the γ line of bismuth even though the α' , α and β lines appeared very black.

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